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BY

HOWARD G. WILSHIRE

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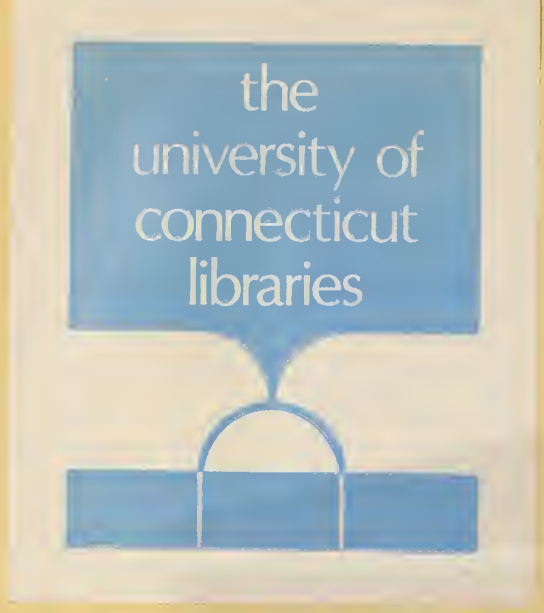

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PROPYLITIZATION OF TERTIARY VOLCANIC ROCKS NEAR EBBETTS PASS, ALPINE COUNTY, CALIFORNIA

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ABSTRACT

In the Ebbetts Pass region propylitized rocks are confined chiefly to the early volcanic breccias which were deposited by sedimentary agents in large interior basins on a prevolcanic erosion surface.

The secondary mineralogy of the propylitized rocks is described, and variations in the type and proportions of secondary minerals replacing the same primary mineral are discussed. These variations, as they occur within a given rock type, are caused by: (1) variations in original composition of the primary minerals; (2) local changes in composition of the altering solutions caused by interaction of fluids and solid rock; and (3) an apparent effect due to the way thin sections are cut. Sericitization is confined to acid rocks, and to basic rocks adjacent to altered acid rocks. This difference in secondary mineralogy is attributed to differences in composition of primary minerals in the rocks and to mobility of potash and possibly soda.

Although the geologic evidence does not rule out other hypotheses, it strongly supports heating, by intrusive magmas, of ground water contained in volcanic breccias as the principal cause of propylitization. CO_2 may also have been derived from these magmas, but the origin of silica cementing the breccias is not known. The evidence is strongly against autohydration as a cause of propylitization of the breccias.

INTRODUCTION

Two zones of propylitic rocks near Ebbetts Pass, Alpine County, California, are described in this report. Although the area is mentioned in a number of reconnaissance studies, the only detailed work is that of Curtis (1951). In addition, two detailed studies of propylitization in adjacent areas were made by Coats (1940) and Halsey (1953). For this study, an area of 70 square miles was mapped on aerial photographs on a scale of 2,000 feet to the inch and then transferred to Forest Service drainage maps with a scale of 1 inch = 2 miles. Four months were spent in field work during the summers of 1954 and 1955.

Many of the ideas presented here were obtained in discussions with colleagues at the University of California. It is a pleasure to acknowledge the great value of their critical attitudes in the discussions. I am especially indebted to Professors Garniss Curtis and Howel Williams for reviewing the manuscript critically and offering many helpful suggestions. In addition, Professor Curtis is thanked for visiting the area with me.

GEOLOGIC SETTING

Before late Tertiary volcanism, an undulating surface had been carved on the metamorphic and plutonic rocks of the Sierra Nevada. The maximum relief in the present crest region was approximately 2,500 feet. It is likely, as Halsey (1953) suggested, that large interior basins existed from the present crest eastward.

Volcanism began in late Miocene or early Pliocene time with eruption of rhyolite tuffs. Although these are now preserved in prevolcanic stream channels, the

drainage pattern was not materially changed as it was by the following voluminous andesite eruptions (Curtis, 1954).

The early andesites, ranging in thickness up to 2,000 feet, consist almost entirely of andesite breccias interbedded with andesitic sandstones, conglomerates, lahars, and some lake deposits. Precise vents have not been found, but the nature of the eruptions is better known. The absence of pumice, scoria, and bombs suggests that the deposits are not pyroclastic. It is probable that the andesites were erupted as autobrecciated flows which were then rapidly eroded, the debris being redeposited on flood plains within large interior basins and ultimately inundating all but the highest areas of the old topography.

This period of eruption and rapid erosion was soon followed by renewed outpouring of massive and autobrecciated flows, predominantly andesitic but including all members of the calcic series. Their sources are represented by innumerable intrusive bodies in a belt roughly parallel to the present crest. The end of volcanism was marked by intrusion of large rhyolite and dacite domes. At that time the Ebbetts Pass region probably consisted of a large cone encompassing Silver and Highland peaks and parasitic or independent cones near Raymond Peak and Highland Lakes. Evidence for this view lies in the distribution of late rhyolite tuffs and flows and clusters of intrusive bodies (fig. 1).

At some time, probably during the latter part of the volcanic cycle, the early volcanic breccias were extensively propylitized. Finally, during and following volcanism, the area was block-faulted, elevated, and deeply dissected.

DEFINITION OF PROPYLITIZATION

Coats (1940), in an extensive review of the literature, traced the history of the term propylite from its introduction in 1868 by von Richtofen to 1940 and formulated a new definition based on the literature and his own work on the alteration along the Comstock Lode, the type locality for propylitic rocks (Zirkel, 1873). Von Richtofen believed the propylites to have formed by consolidation of a propylitic magma and to represent the first Tertiary lavas. Becker (1882) and most subsequent authors considered propylites to be alteration products of andesite and called the process of alteration propylitization. According to Coats (1940, p. 16), propylitization is the process of alteration of andesite which results in formation of epidote comparable in size with feldspar phenocrysts, secondary albite replacing plagioclase, and chlorite, calcite, and epidote replacing the mafic minerals.

Unfortunately, most authors have given only passing attention to propylitic rocks. Secondary minerals mentioned indicate neither the frequency of occurrence nor those in proximity. It is uncertain, therefore, whether minerals such as epidote and secondary albite required by Coats' definition are invariably present. In addition, most propylitized zones contain other members of the calc-alkaline or calcic series as well as andesite, and these have also responded to the same process of alteration. It seems desirable, therefore, not to restrict the definition of propylitization to alteration of andesite alone, but to include in it alteration of any rock by a process, unattended by strong deformation, which produces in andesites some combination of the above secondary minerals. The term will be so used in this study.

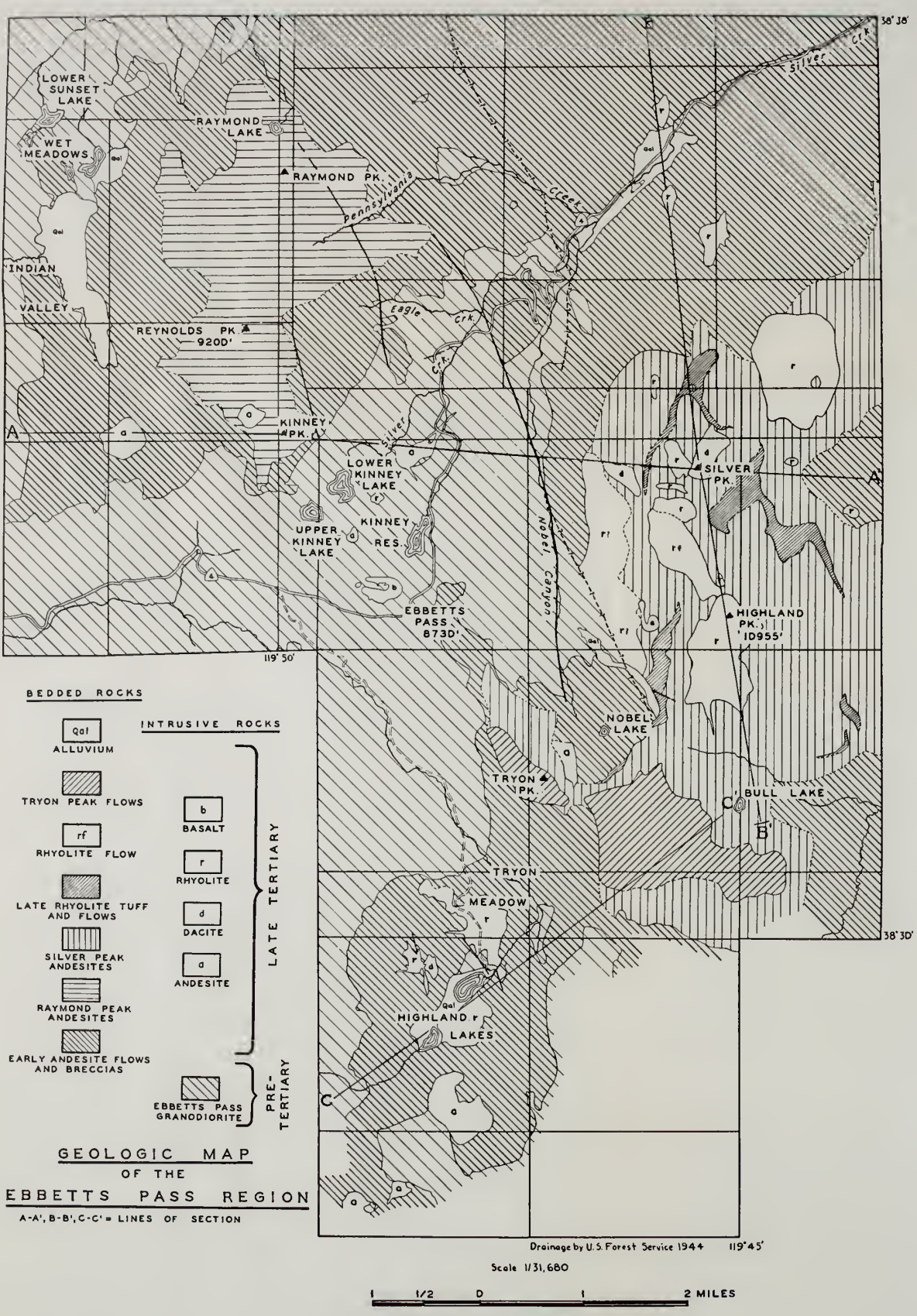

Fig. 1. Geologic map of the Ebbetts Pass region.

To accompany Howard G. Wilshire, "Propylitization of Tertiary Volcanic Rocks near Ebbetts Pass, Alpine County, California," Univ. Calif. Publ. Geol. Sci., Vol. 32, No. 4.

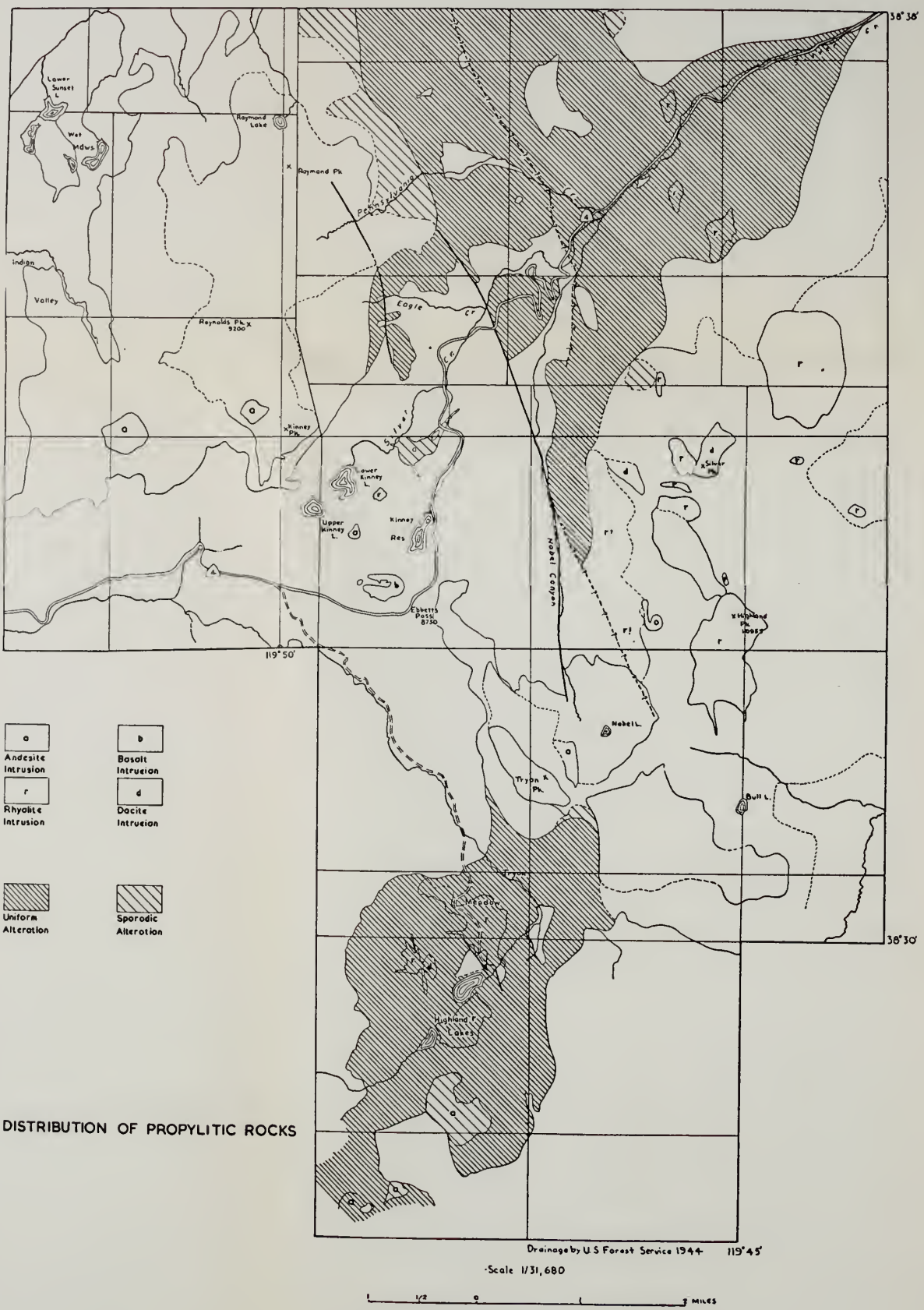

Fig. 2. Distribution of propylitic rocks.

To accompany Howard G. Wilshire, "Propylitization of Tertiary Volcanic Rocks near Ebbetts Pass, Alpine County, California," Univ. Calif. Publ. Geol. Sci., Vol. 32, No. 4.

The secondary mineral assemblages to be seen in propylitic rocks recur in spilites and metamorphic rocks of the greenschist facies. However, comparison of mineral assemblages in terms of broad mineral groups such as carbonate or chlorite is not adequate. The work of Goldsmith *et al.* (1955) suggests that there may be consistent differences between the carbonates formed under different geologic conditions. Until enough data are available to clarify such points, it is desirable to limit the term propylite to rocks in volcanic terrains which have not been severely deformed. This restriction is consistent with general usage.

FIELD CHARACTERISTICS AND OCCURRENCE OF PROPYLITIC ROCKS IN THE EBBETTS PASS REGION

Propylitized andesites are easily recognized by their distinct bluish to greenish color and their response to erosion. The general softening effect of the alteration results in development of subdued topography contrasting with the rugged topography of unaltered rocks. The effect of the alteration on acid rocks is bleaching which accentuates the color contrast between these and propylitized andesites.

Macroscopic textural features are generally well preserved. Cross-bedding in the andesitic sandstones, rounded and angular boulders and cobbles in the conglomerates and breccias are retained. However, the effect of alteration is to soften the rock fragments and harden the matrix so that the differential weathering of rock fragments and matrix is minimized. The porphyritic texture of the volcanic rocks is excellently preserved, and many pseudomorphs of the original minerals may be distinguished by the naked eye.

In the region of Ebbetts Pass, the propylitic rocks occur in the lower part of the volcanic section, and, where alteration is uniformly severe, they are limited essentially to the early volcanic breccias (fig. 2). In the Silver Peak area the volcanic breccias are succeeded by thick massive and autobrecciated flows. Here the transition from uniformly propylitized rock to unaltered rock is very rapid (within 10 to 100 feet). Near Raymond Peak the limits of alteration are much more difficult to ascertain. The early volcanic breccias are succeeded by thin flows intercalated with andesite breccias. In this upper zone, alteration is sporadic, varying widely in degree over short distances. West and north of Raymond Peak the alteration, even in the early volcanic breccias, dies out. Near Highland Lakes the entire section, excluding intrusive bodies, is made up of propylitized andesite breccias except at the eastern extremities where the breccias thin and pass under unaltered dacite flows. There are no exposed contacts between the dacites and propylitized breccias.

PETROGRAPHY OF PROPYLITIZED ROCKS

METHODS OF INVESTIGATION

Plagioclase compositions were determined with the universal stage using Turner's (1947) method and von der Kaaden's (1951) data on volcanic plagioclase. The clay minerals, chlorites, and micas were identified by X-ray powder patterns. Iron oxides were studied in polished section, and the carbonates identified by measuring the ω refractive index. Where ω corresponds to that of calcite, the mineral is so designated. Carbonates with ω greater than that of calcite are iden-

tified by this value since a mineral name is not warranted unless the composition is known. Some of the data on chlorites, clays, and micas are given on page 248. All other identifications were made using the standard petrographic microscope.

EARLY VOLCANIC BRECCIAS

All members of the calcic series from olivine basalt to rhyolite are represented in the early volcanic breccias. Andesites predominate, and most of the acid rocks (including fragments of granodiorite and quartz monzonite) occur near the base of the section. Massive flows are very rare, but massive and brecciated intrusions are common.

Except where alteration was extremely severe, original microtextures are perfectly preserved. Primary minerals usually may be identified by the forms of pseudomorphs or because parts remain unaltered. Secondary minerals are discussed under the headings of the primary minerals which they replace.

Alteration of Primary Minerals

Olivine.—Olivine is always completely altered. The usual secondary aggregate consists of magnetite, calcite, and quartz in variable proportions. In one specimen, chlorite is present rather than magnetite. One or more carbonates ($\omega > 1.658$, < 1.670) are usually present with calcite.

Orthopyroxene.—Orthopyroxene is also completely replaced, usually by a mixture of chlorite and montmorillonoid[1] (see table 1) and calcite or quartz. In some specimens it is entirely replaced by chlorite.

Clinopyroxene.—Clinopyroxene is partly or completely replaced usually by one of three secondary aggregates: chlorite, carbonate, quartz; chlorite, carbonate, epidote; chlorite, carbonate, and magnetite or hematite. The carbonate is usually calcite or near calcite but may have a value of ω as high as 1.69. There is no apparent correlation between the value of ω and the other constituents of the secondary aggregate. Some pseudomorphs consist entirely of calcite or of a montmorillonoid and chlorite. Where pyroxene-bearing rocks are adjacent to granodiorite or rhyolite fragments, the aggregate may contain sericite in addition to the above minerals.

Hornblende.—Hornblende is usually completely replaced. There is considerable variation in the alteration products depending, in part, on the rock type containing the hornblende. In andesites the only secondary aggregate which appears with regularity consists of chlorite, calcite, and epidote. Epidote is present typically as minute granules preserving the cleavage traces of the hornblende (pl. 33, *a*). Other secondary aggregates consist of calcite, magnetite, chlorite, and quartz; or a montmorillonoid, chlorite, and epidote. In acid rocks, sericite with a montmorillonoid (?) is common in association with epidote, quartz, or calcite.

Biotite.—Biotite is the most resistant to alteration of all the mafic minerals. Where it is altered, the nature of the secondary aggregate depends partly on the rock type. In andesites and dacites, the secondary aggregate usually consists of some combination of a montmorillonoid, chlorite, and epidote. In a few specimens, carbonate or sericite is present. In rhyolites the secondary aggregate is usually

[1] The term montmorillonoid denotes the mineral group to which montmorillonite belongs.

muscovite, or muscovite with either epidote or magnetite. Rarely, a montmorillonoid (?) occurs with muscovite.

Plagioclase.—Plagioclase exhibits extreme variation in degree of alteration even within the limits of a thin section. There may or may not be preferential replacement of zones in single crystals. Some phenocrysts are altered although the accompanying microlites are fresh. The secondary aggregates vary, depending partly on the enclosing rock type and partly on the composition of adjacent rock fragments. In andesites, the most common secondary aggregate consists of calcite and a colorless to pale green material which may be optically isotropic or birefringent (a montmorillonoid ?). Quartz is common in the aggregates. Epidote and clinozoisite form large crystals replacing the plagioclase of granodiorite, dacite, and some rhyolite fragments. These minerals are very rare in secondary aggregates replacing the feldspar of andesites. Where epidote and clinozoisite are present calcite is subordinate or absent. In addition to these minerals, sericite is very common in the plagioclase of acid rocks or of andesites and olivine basalts adjacent to altered acid rocks. In some specimens the zonal structure of plagioclase is preserved by different grain sizes of secondary sericite (pl. 33, *b*).

Alkali feldspar.—Most alkali feldspars are only partly altered. Secondary aggregates almost always contain sericite and commonly contain calcite, epidote, and clinozoisite. Occasionally quartz, hematite, or a pale green material with moderate birefringence (a montmorillonoid ?) is present. Epidote and clinozoisite are sporadically distributed even within the limits of a thin section.

Quartz, magnetite, and apatite.—These minerals remain essentially unaltered. In rare cases magnetite is replaced by specular hematite. Whether this is the result of propylitization is not known, for most of the magnetite in the altered zones is fresh. In many specimens the opaque rims around hornblende, commonly identified as magnetite, are partly altered to earthy hematite. In polished section magnetite, which makes up less than 25 per cent of the opaque rims, appears to be fresh.

Vesicle-filling and Alteration of the Groundmass of Rock Fragments

Most vesicle-fillings consist of chlorite, sericite, and quartz or calcite. The sericite is usually not recognizable optically, and nothing is known about its composition. In some examples opal is present. It is noteworthy that the green material which occurs as a vesicle-filling in rocks outside the propylitic zones has proved, in all specimens studied, to be an iron- and/or magnesium-rich montmorillonoid.

The groundmass, commonly glassy in unaltered rocks, has been converted invariably to holocrystalline aggregates. Many of the minerals are too fine-grained to be identified; however, quartz and carbonate (calcite or a carbonate with ω near that of calcite) are commonly distinguishable. The groundmass of basalts and andesites usually contains pale green to brownish material of variable crystallinity. A colorless micaceous mineral, probably sericite, occurs in some basalts and andesites adjacent to altered acid rocks. The groundmass of acid rocks invariably contains sericite and quartz, and usually contains calcite and a pale green optically isotropic material.

TABLE 1

X-RAY DATA

Measured d-spacings																				
1	I[a]	Id[b]	2	I	Id	3	I	Id	4	I	Id	5	I	Id	6	I	Id	7	I	Id
14.43	8	C	14.24	10	C	13.72	10	M	14.24	8	M	14.24	9	C	14.43	10	C	14.24	7	C
10.11	8	S	7.11	10	C	10.06	6	S	5.14	4	S ?	7.14	10	C	7.16	10	C	7.09	6	C
7.12	9	C	4.78	4	C	4.54	6	M,S	4.53	W	M,S	4.77	4	C	4.80	W	C	4.78	2	C
4.75	W	C	4.61	4	C	4.36	W	S	4.34	2	Cr,S	4.62	W	C	3.56	9	C	4.59	2	C
4.51	6	C,S	4.48	4	C	4.06	4	S	4.08	10	S	3.56	10	C	3.35	2	C	3.79	W	U
4.36	2	S	3.56	9	C	3.73	W	U	3.91	4	S	3.44	2	U	3.20	3	C	3.54	4	C
4.14	10	S	3.37	W	U	3.62	4	U	3.78	W	U	3.20	W	C	3.03	6	Ca	3.35	3	Q
3.67	1	U	3.19	W	C	3.33	3	Q,S	3.66	W	S	3.03	W	Ca	2.71	W	U	3.04	10	Ca
3.56	2	C	3.04	W	Ca	3.22	3	S	3.22	6	M,S	2.85	2	C	2.523	W	C	2.85	W	C
3.34	3	S	2.85	W	C	3.10	2	F ?	2.523	2	Cr,S	2.66	W	C	1.541	4	C	2.71	W	U
3.07	3	Ca ?	2.60	W	C	3.02	2	Ca	2.358	2	M	2.60	4	C				2.60	W	C
2.85	W	C,S	2.55	W	C	2.67	W	M	2.288	2	M,S	2.55	4	C				2.491	W	C
2.67	1	C	2.474	W	C	2.58	6	S,M	1.643	2	Cr,M,S	2.451	4	C				2.279	3	C
2.57	6	C,S	2.384	W	C	2.420	3	S,M	1.622	2	Cr,S	2.389	4	C				2.091	2	C
2.489	W	S	2.279	W	C	1.526	W	M ?	1.485	5	M,S	2.271	2	C				1.905	2	C
2.389	W	C,S	1.545	7	C	1.512	3	M				2.010	3	C				1.867	2	C
1.543	4	C	1.512	3	C							1.543	5	C				1.538	4	C
1.505	5	S										1.509	2	C						

[a] = visually estimated intensity of each line based on a scale of 10 (the most intense line in any pattern) or less. W = very weak line.

[b] Id = identification of each line. M = montmorillonoid; C = chlorite; Ca = calcite; Cb = some cargonate other than calcite; Q = quartz; S = sericite; Cr = cristobalite; F = feldspar; U = unidentified.

1. Vesicle-filling from propylitic rock.
2. Vesicle-filling from propylitic rock.
3. Vesicle-filling from unaltered rock.
4. Vesicle-filling from unaltered rock.
5. Pseudomorphs after hornblende.
6. Pseudomorphs after hornblende.
7. Pseudomorphs after clinopyroxene.

TABLE 1—*Continued*

Measured d-spacings																	
8	I	Id	9	I	Id	10	I	Id	11	I	Id	12	I	Id	13	I	Id
14.15	10	C	13.92	6	C	13.97	10	M	13.15	10	M	10.44	8	S	14.15	10	C
7.12	9	C	7.05	5	C	4.59	4	M	4.57	9	M	4.51	8	S	10.02	5	S
4.75	4	C	4.49	3	C	4.13	W	U	3.22	5	F ?	4.25	5	S	7.09	10	C
4.60	4	C	4.34	3	U	3.35	4	Q	2.63	4	M	3.59	5	S ?	4.73	6	C
4.28	3	U	3.86	W	Ca ?	3.18	8	F ?	2.524	3	M	3.34	10	Q	4.50	W	S
3.55	5	C	3.52	W	C	3.04	2	Ca	1.532	8	M	3.05	3	Ca	3.66	W	U
3.35	10	Q	3.34	10	Q	2.97	2	M,Cb ?				2.68	W	U	3.55	10	C
3.20	W	C	3.20	W	C	2.88	2	Cb ?				2.58	7	S	3.33	5	Q
2.85	W	C	3.03	10	Ca	2.84	1	M				2.460	W	S	3.03	5	Ca
2.59	4	C	2.71	2	U	2.71	1	M				2.398	W	S	2.83	3	C,S
2.54	4	C	2.521	W	C	2.54	2	M				2.288	W	C	2.59	3	C,S
2.442	4	C	2.279	2	C	2.505	1	U				1.818	3	U	2.55	3	C,S
2.271	W	C	2.128	W	U	2.461	1	U				1.656	W	S	2.494	W	S
2.011	W	C	2.087	W	C	2.117	W	U				1.544	3	U	2.451	2	S
1.823	W	C	1.906	W	U	2.067	W	Ca				1.504	4	S	2.391	2	C,S
1.672	W	C	1.869	W	C	2.025	W	U							2.269	1	C
1.631	5	C	1.819	W	C	1.990	W	Ca							2.145	W	U
1.598	W	C	1.693	W	C	1.966	W	U							2.089	W	C
			1.599	W	U	1.740	W	M							2.003	3	C,S
			1.532	2	C	1.538	4	M							1.888	W	C
						1.490	3	M							1.822	W	C
						1.475	3	U							1.663	W	C,S
															1.568	2	S ?
															1.544	3	C
															1.506	2	S

8. Pseudomorphs after clinopyroxene.
9. Pseudomorphs after hypersthene, propylitic rock.
10. Pseudomorphs after hypersthene, nonpropylitic rock.
11. Pseudomorphs after olivine.
12. Cement in andesite breccia.
13. Pseudomorphs after biotite.

Vein Minerals and Minerals Cementing the Breccias

Ore minerals are excluded from this treatment since the mines in the area are no longer accessible, and previous descriptions of the occurrence of ore minerals are inadequate. Calcite-quartz veins are very common in the propylitic zones. Chlorite is present in a few veins, and sometimes a zeolite (stilbite in one case) is present with calcite. Pyrite occurs rarely and is always associated with granular quartz rather than with calcite. Outside the altered zones opal predominates as a vein mineral, and chlorite and calcite are rare or absent. The joint surfaces in propylitized rocks are usually coated with chlorite, calcite, and abundant fine-grained quartz. Occasionally epidote is abundant.

Fine-grained quartz is always present in the cementing materials of the breccias. In most specimens a very fine-grained colorless to green micaceous material is present. The one powder pattern made of this indicates the presence of sericite and possibly a montmorillonoid. Calcite may or may not be present and is always subordinate to quartz. Hematite is very common, and in places makes up as much as 75 per cent of the cement. The ratio of hematite to quartz varies rapidly in distances of less than a foot. It is often difficult, especially with carbonates, to determine whether a mineral is part of the cement or has replaced the finely granulated rock and mineral debris of the matrix.

EXAMPLES OF TRANSITIONAL PROPYLITIZATION

Three rock bodies, all near the periphery of the altered zones, were studied in detail because they illustrate transitions from highly propylitized to fresh or nearly fresh rock.

Hornblende-Biotite-Pyroxene Andesite Neck

The freshest rock is porphyritic with phenocrysts of plagioclase (An_{43-55}), hornblende, and biotite set in an intersertal groundmass composed of stubby plagioclase microlites, iron ore, apatite, and interstitial montmorillonoid. This may be a product of deuteric alteration before propylitization (see p. 252) and will be treated as such here, although the distinction is tentative. Biotite occurs as ragged flakes enclosed in hornblende phenocrysts, and the clinopyroxene as small granules in pyroxene-magnetite-plagioclase coronas around the hornblende phenocrysts. Vesicles contain abundant cristobalite and occasionally a carbonate.

The first manifestation of propylitization is a partial or complete inversion of cristobalite to quartz (pl. 34, *a*) and partial replacement of plagioclase by calcite. Preferential replacement of certain zones in plagioclase phenocrysts is common. As alteration increases, some plagioclase phenocrysts are completely replaced by calcite, a finely divided micaceous green mineral and sericite (?). Core zones of plagioclase microlites are replaced by an optically isotropic green material or by carbonate. In the same specimens quartz is much more abundant in the groundmass and vesicles. Cristobalite is replaced by granular quartz pseudomorphs. After alteration of plagioclase began, hornblende and pyroxene were completely replaced by chlorite, carbonate (ω ranging from that of calcite to 1.70) and epidote. No

transitions were observed in this rock in which hornblende and pyroxene are partly altered. Biotite, even in the most severely altered specimens, remains fresh (pl. 34, *b*), and both apatite and magnetite are unaltered.

Autobrecciated Pyroxene-Hornblende Andesite Flow

This rock is porphyritic with large phenocrysts of augite, plagioclase (An_{56-60}), and hornblende with thick opaque rims, set in a pilotaxitic groundmass. In the freshest rock hypersthene phenocrysts are largely or completely replaced by carbonate and an iron- and/or magnesium-rich montmorillonoid. The groundmass consists of plagioclase and clinopyroxene microlites with some interstitial material which is optically identical with the secondary aggregates replacing the hypersthene. This same material also occurs in irregular patches in plagioclase phenocrysts and in vesicles.

In the first phase of propylitization, augite phenocrysts show incipient alteration to chlorite (?) and calcite (?), whereas hornblende is either fresh or largely replaced by chlorite, calcite, and epidote where gaps occur in the opaque rims. A green mineral in the groundmass and in plagioclase is optically identical with the chlorite replacing hornblende. The form of the clinopyroxene phenocrysts in this rock is very similar to that of hypersthene, so that they are indistinguishable unless relicts remain. Except for the alteration described above, plagioclase is essentially unaffected in this stage, even where phenocrysts are traversed by carbonate veinlets (pl. 35). Vesicle-fillings include chlorite, calcite, and quartz. In specimens exhibiting complete alteration of the mafic minerals, plagioclase phenocrysts and microlites show incipient replacement by calcite with marked preference for certain zones in the plagioclase. Opaque rims around hornblende phenocrysts have large gaps and are partly altered to earthy hematite. The groundmass contains abundant hematite. In the most highly altered parts of the flow (the autobrecciated base), plagioclase phenocrysts are largely replaced by calcite. The remaining parts of the feldspar phenocrysts may have been replaced by albite. Plagioclase microlites, however, exhibit no alteration beyond that described above. Magnetite and apatite are unaltered.

Massive Pyroxene Andesite Flow

This rock is porphyritic with phenocrysts of plagioclase (An_{53-55}) and augite, set in a pilotaxitic groundmass composed of plagioclase and clinopyroxene microlites and iron ore. Hypersthene phenocrysts are completely replaced by an iron- and/or magnesium-rich montmorillonoid and calcite in the freshest rock.

In the first stage of propylitization, clinopyroxene phenocrysts were replaced along fractures and cleavages by chlorite (?). The groundmass is crossed by an intricate network of quartz-carbonate veinlets which either pass through plagioclase phenocrysts along fractures and cleavages or appear to replace large segments of the plagioclase. The latter may be due to the way in which the thin section is cut. In some parts of the groundmass, however, the network of veinlets is absent and larger veinlets occupy small shears. These larger veinlets widen where they cross plagioclase, probably indicating replacement. In these specimens the material replacing hypersthene is chlorite, calcite, and montmorillonoid. As

alteration becomes more severe, clinopyroxene is completely replaced by chlorite, carbonate (ω less than 1.670) and epidote. There are concentrations of fine-grained magnetite, not present in the fresh rock, surrounding the clinopyroxene phenocrysts. Plagioclase phenocrysts show no further alteration and the plagioclase microlites are unaltered. Chlorite-calcite pseudomorphs after hypersthene are rimmed and occasionally traversed by veinlets of granular quartz which do not extend into the groundmass.

DISCUSSION OF THE MINERALOGICAL DATA

ORDER OF SUSCEPTIBILITY OF PRIMARY MINERALS TO PROPYLITIZATION

Evidence of the order of alteration of primary minerals in the propylite environment is usually ambiguous. It was shown (p. 250) that the occurrence of partly altered minerals with completely altered minerals is not proof that the partly altered ones were attacked later. This interpretation is valid only if some mineral is completely unaltered or where transitions from fresh to altered rock may be observed. Even then caution must be exercised; for example, opaque sheaths around hornblende crystals may protect the hornblende in early stages of alteration.

As noted by Coats (1940) and Curtis (1951), hypersthene is almost always altered, the alteration showing no relation to propylitic zones. This is also true of olivine, although it is usually only marginally altered in rocks outside the propylitic zones. For this reason, Coats attributed the alteration to deuteric processes before propylitization. X-ray powder patterns indicate that the mineral replacing hypersthene (called bastite or chrysotile by Coats and Curtis) outside the propylitic zones is an iron- and/or magnesium-rich montmorillonoid. Vesicle-fillings and joint-surface coatings consist of the same material, although these may also include a mica. It was noted in the example of transitional alteration that the birefringence of the montmorillonoid approaches that of chlorite in the propylitized rocks. X-ray powder patterns of this mineral indicate the presence of a magnesian chlorite and, in some cases, a montmorillonoid and chlorite. Since iron is removed from the mafic minerals to form iron oxides, iron-magnesian montmorillonoid is probably unstable in the propylitic environment and is replaced by chlorite. According to Grim (1953, p. 69), the chlorite structure consists of alternate micalike and brucitelike layers for which the general compositions are, respectively $(OH)_4(Si,Al)_8(Mg,Fe)_6O_{20}$ and $(Mg,Al)_6(OH)_{12}$. The current conception of the montmorillonite structure is two silica tetrahedral sheets with a central alumina sheet (Grim, 1953, p. 55). Replacement of Al by Mg or Fe gives saponite or nontronite. Fournier (personal communication) suggests that an iron-magnesian montmorillonoid may be converted to chlorite by removal of the silica sheets in alternate layers of the montmorillonoid and accompanying hydration of the remaining octahedral layer. Al may be substituted for Fe in the central sheet of the brucite-like layer of chlorite. Further substitution of Al for Si in the silica sheets will provide the bonding forces for the chlorite. This removal of silica possibly accounts for the appearance of quartz in pseudomorphs after hypersthene in propylitized rocks.

Biotite is commonly unaltered in rocks otherwise highly propylitized. It may be placed with confidence near the end of the list of susceptibility. The only primary minerals less susceptible than biotite are quartz, magnetite, and apatite.

The relationships between the alteration of hornblende, clinopyroxene, and plagioclase are usually ambiguous. However, in the examples of transitional alteration described above, plagioclase of the andesite neck was attacked first, that of the pyroxene-hornblende andesite flow was attacked after the mafic minerals, and that of the pyroxene andesite flow was possibly attacked simultaneously with the pyroxene. Coats (1938) described a separate type of propylitization in which plagioclase was altered to calcite, albite, and zeolite, and the mafic minerals are fresh. He suggested that this order of susceptibility represents lower temperature conditions of alteration and solutions relatively enriched in CO_2. No evidence is given for this inference, and I can find none. Since most of the propylitized rocks provide no reliable information on the order of susceptibility of the primary minerals, this inference appears unjustified.

ALBITIZATION OF PLAGIOCLASE

Albitization of the plagioclase, common in other propylitic rocks (e.g., those described by Kato, 1931, and Coats, 1940), is rare if not absent in the Ebbetts Pass rocks. Furthermore, no correlation was found between the composition of plagioclase phenocrysts and their degree of alteration. The range of composition in any rock type is the same as that found in the plagioclase of corresponding unaltered rocks. With the one exception cited on page 250, the only rocks in which albitization of the plagioclase may have occurred are rhyolites.

VARIATIONS IN THE PROPORTIONS AND TYPES OF SECONDARY MINERALS REPLACING THE SAME PRIMARY MINERAL

Two cases will be described: variations within one rock type in the proportions and types of secondary minerals replacing a particular primary mineral; and variations which may be correlated with different rock types having some primary minerals in common (specifically plagioclase, hornblende, and to a lesser degree clinopyroxene and biotite, which occur in a wide range of rock types).

These variations result from several causes: (1) variation in the initial composition of the primary mineral; (2) an apparent effect due to the way in which the thin section is cut; and (3) changes in the composition of solutions caused by local interaction between solutions and solid rock.

Variations Within the Limits of One Rock Type

The proportions of chlorite, calcite, and epidote replacing hornblende in hornblende andesite may vary within the limits of a thin section or, in the early andesite breccias, in different fragments of hornblende andesite several miles apart.

The effect of variation in initial composition of primary minerals is not easy to evaluate, especially with hornblende, biotite, and clinopyroxene, the compositions of which are not known. If these mineral groups behave as plagioclase does, the effect of variations in original composition is unpredictable. A statistical study was made of plagioclase compositions in several unaltered rocks, and the frequency

curves proved to be extremely erratic. In some rocks all the plagioclase phenocrysts have the same composition within the limits of error in determination; in other rocks the range in composition may be as high as 40 per cent anorthite. An additional difficulty is that the composition of plagioclase as determined by universal stage methods is independent of grain orientation, whereas the proportions of secondary minerals as determined by point counter methods depend on the way in which the thin section is cut, because secondary minerals are not evenly distributed through the pseudomorphs.

The way in which a thin section is cut may also cause an apparent variation in the type of secondary minerals replacing the same primary mineral. For example, epidote replacing alkali feldspar is commonly present as a single crystal. If calcite is present it usually occurs in a discontinuous zone surrounding the epidote, although sericite is sporadically distributed through the rest of the phenocryst. It is possible, therefore, to cut sections through such a phenocryst that will show many combinations of these secondary minerals. A prohibitive number of thin sections would have to be cut to prove whether or not these variations are real.

Local changes in composition of the solutions are suggested where sericitization of plagioclase has taken place in andesites and basalts adjacent to acid rocks in the basal breccias. Plagioclase of intermediate and basic rocks more than a few feet distant from altered acid rocks is typically converted to calcite.

Although most of the secondary mineralogical variations cannot be related to such features as sericite "halos" around altered acid rocks, there is good reason to believe that some of the variations are real and are related to changes in composition of the solutions. It is clear from the nature of the secondary minerals that H_2O and CO_2 are added and, in most mafic minerals, iron is removed. In some cases, for example alkali feldspar replaced by epidote and calcite, other materials are also introduced and removed. These changes will be discussed later.

It is well to recall at this point the brecciated character of most of the propylitized rocks. If the breccias were uncemented, then altering solutions had access to a very large surface area through openings of large size, in which, according to Holser (1947), the movement of material is relatively unrestricted. Movement of material to the surface of rock fragments is effected by movement of the solutions as a whole and/or by diffusion along concentration gradients within a fluid medium. As the solutions penetrate the rock fragments, however, they must necessarily pass through openings of smaller size. The barriers opposing migration of material to and from the constituents of the rock fragments are much more selective than in the large openings. Selectivity of the barriers depends not only on the size of the openings but also on interactions (chemical reaction, adsorption, and so on) between the diffusing material and the walls of the openings. On the scale with which we are dealing, the fabric and composition of the rock are completely heterogeneous. Solutions arriving and leaving all crystals of the same type, for example alkali feldspar, in the same rock must, therefore, vary in composition unless they have passed along identical routes or the effects of passage along different routes are compensating. Both of these conditions are very unlikely in view of the heterogeneity of the rock.

Complete replacement of one alkali feldspar phenocryst and partial replacement of another by calcite means that more of the feldspar was removed in one case than the other and not that the entering solutions contain varying amounts of calcium carbonate. Presumably solution and removal, as required by this replacement, are controlled both by the composition of entering solutions and the composition and texture of surrounding rock through which out-going solutions must pass.

Variations Correlated with Different Rock Types

The broad correlation between the rock type containing a primary mineral and the secondary minerals replacing it may reflect two factors: differences in composition of the primary minerals in different rock types; and movement of potash and/or soda. The composition of plagioclase (and presumably of hornblende and clinopyroxene) varies markedly from basalt to rhyolite. This difference may influence the formation of different secondary phases in acid rocks from those in andesites or basalts. It will be noted from the mineralogical data, however, that differences in secondary minerals between acid and basic rocks are usually expressed in the occurrence of sericite in all three of the main primary groups (plagioclase, hornblende, and clinopyroxene) in acid rocks. Interchange of material between primary minerals of acid rocks is indicated by replacement of alkali feldspar and sodic plagioclase by calcite and epidote and of mafic minerals such as hornblende by sericite. Movement of potash and possible soda beyond the acid rocks is suggested by sericite "halos" in basic rocks surrounding altered acid rocks.

CHEMICAL ANALYSES

Six chemical analyses were obtained, three of fresh rock and three of their propylitized equivalents. The petrography of nos. 1 to 4 (table 2) is described in the section on transitional alteration; nos. 1 and 2 were obtained from the andesite neck and nos. 3 and 4 from the pyroxene andesite flow. Specimens 5 and 6 were taken from a biotite-hornblende dacite flow and exhibit the alteration described in the petrography of the volcanic breccias. The analyses as given in table 2 represent the weight per cents of the various oxides recalculated to 100 per cent excluding the adsorbed water.

Several factors must be considered in interpreting the changes which have taken place in the alteration. These include the sampling error, change in density, and the analytical error.

Since only one analysis was made for each fresh rock and its altered equivalent, no data are available on the range of weight per cents of the various oxides in samples from different parts of the same rock. An attempt was made to reduce this error by combining samples taken from various parts of the flows and the andesite neck. Only one specimen of no. 6 was obtained.

Density measurements are tabulated in table 2. Because the rocks have a variable porosity, both the bulk density and density of the solids (using powdered material) were measured. The increase in bulk density from fresh to altered rock probably represents complete filling of vesicles in the altered rocks. The difference in densities of the solids between fresh rocks and their propylitized equivalents is within the limits of error of the determinations. This is primarily a sampling

TABLE 2

CHEMICAL ANALYSES RECALCULATED TO 100 PER CENT EXCLUDING H_2O

	1	2	3	4	5	6
SiO_2	58.77	55.03	54.96	57.48	65.68	63.88
Al_2O_3	17.53	17.06	18.23	16.79	16.51	13.71
FeO	1.88	2.73	1.90	2.50	1.53	2.04
Fe_2O_3	4.35	3.51	5.91	2.60	1.98	3.84
TiO_2	0.59	0.50	0.88	0.69	0.44	0.33
MnO	0.07	0.09	0.09	0.07	0.07	0.07
CaO	6.27	6.58	6.22	6.77	3.44	3.70
MgO	3.58	4.22	4.04	3.60	1.73	1.77
K_2O	1.85	1.63	2.12	0.44	3.24	2.38
Na_2O	2.84	2.35	3.35	1.95	3.32	3.14
H_2O+	2.10	2.60	1.96	2.58	1.93	1.71
CO_2	nil	3.52	nil	4.32	nil	3.20
P_2O_5	0.17	0.18	0.34	0.21	0.13	0.23
H_2O- 105° C	1.68	0.96	1.32	1.38	0.18	0.39
Bulk density	2.24	2.44	2.42	2.44	2.13	2.37
Density of solids	2.69	2.70	2.74	2.69	2.64	2.70

1. Acid andesite neck ¾ mi. northeast of Lower Kinney Lake.
2. Propylitized equivalent of 1.
3. Pyroxene andesite flow 2 mi. northeast of Silver Peak.
4. Propylitized equivalent of 3.
5. Dacite flow ½ mi. north of Asa Lake.
6. Propylitized equivalent of 5.

Analyst: W. H. Herdsman, Glasgow, Scotland.

TABLE 3

ANALYSES CALCULATED IN TERMS OF GMS/CC × 100

	1	2	3	4	5	6
SiO_2	158 ± 6	149 ± 6	150 ± 5	155 ± 5	173 ± 6	175 ± 9
Al_2O_3	47 ± 2	46 ± 2	50 ± 2	45 ± 2	44 ± 3	37 ± 2
FeO	5 ± 1	7 ± 1	5 ± 1	7 ± 1	4 ± 1	5 ± 1
Fe_2O_3	12 ± 1	9 ± 1	16 ± 1	7 ± 1	5 ± 1	10 ± 1
TiO_2	2 ± 1	1 ± 1	2 ± 1	2 ± 1	1 ± 1	1 ± 1
MnO	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
CaO	17 ± 1	18 ± 1	17 ± 1	18 ± 1	10 ± 1	10 ± 1
MgO	10 ± 1	11 ± 1	11 ± 1	10 ± 1	5 ± 1	5 ± 1
K_2O	5 ± 1	4 ± 1	6 ± 1	1 ± 1	8 ± 1	6 ± 1
Na_2O	8 ± 1	6 ± 1	9 ± 1	5 ± 1	9 ± 1	8 ± 1
H_2O	6 ± 1	7 ± 1	5 ± 1	7 ± 1	5 ± 1	5 ± 1
CO_2	0 ± 0	10 ± 1	0 ± 0	12 ± 1	0 ± 0	9 ± 1
P_2O_5	0 ± 0	0 ± 0	1 ± 1	0 ± 0	0 ± 0	0 ± 0

error since the measurements are reproducible to the second decimal place. Since changes in weight per cents of some of the oxides are small, the limits of error in density measurements must be considered.

The number of grams per cubic centimeter of each oxide are given in table 3. The limits of error are calculated on the basis of an error of 0.10 in measurement

of density. These figures facilitate determination of true changes in the oxides because of alteration. Where these values differ by more than the calculated error, interpretation of changes in weight per cent is limited only by sampling and analytical errors.

Comparison of the analyses shows that in all three sets alumina, potash, and soda have decreased in the altered specimens. The decrease in alumina in nos. 2 and 4 is so small that a change in density rather than a loss of alumina may account for the differences. The loss in no. 5 is too great to be accounted for by density changes. Loss of alkalis is well outside the limits of error in density determinations except the soda of no. 6. Replacement of plagioclase by calcite requires removal of alumina, soda, and silica and is probably the source of much of these constituents which are removed. Some potash may also be removed from plagioclase, although in no. 6, replacement of biotite by chlorite and of alkali feldspar by calcite provided some of the potash. The biotite of no. 2 is apparently unaltered, and no. 4 contains neither biotite nor alkali feldspar.

Silica, ferric oxide, total iron, and magnesia do not change in the same direction in all altered specimens. The decrease in silica in nos. 2 and 6 may represent actual losses or change in density. The gain in silica of no. 4 is represented in the abundant quartz veinlets in the altered rock. In all three examples ferrous iron has increased; ferric iron decreased in nos. 2 and 4, but increased in no. 6 though the total iron increased in no. 6, decreased in no. 4, and remained the same in no. 2. Conversion of clinopyroxene and hornblende to magnesian chlorite (based on the interpretation of X-ray patterns) results in release of iron. This is generally recombined as iron oxides, either hematite in the breccia cement or magnetite within the altered rocks. If most of the iron in the mafic minerals is ferric iron, recombination as magnetite will result in increase in ferrous and decrease in ferric iron. Also, complete removal of iron combined in mafic minerals would have the same effect since the primary magnetite is unaltered. Total iron should, of course, decrease in this case. In the petrographic description of nos. 3 and 4, it was noted that in altered specimens, chlorite pseudomorphs after clinopyroxene have halos of fine-grained magnetite which is not present in fresh specimens. Although this may explain the increase in ferrous iron in the analysis, I would reasonably expect the total iron to show little variation since it has not been moved far from its source. However, this is the one analysis which shows a marked decrease in total iron. Perhaps this illustrates the limitations of small thin sections and the magnitude of sampling error.

Changes in magnesia are also erratic, though not great. Most of the magnesia is recombined in place as chlorite, but some may be fixed away from its source, either in the cement of the breccias or in other parts of the same rock, as chlorite or a clay mineral. Differential movement within a rock of magnesia, as with lime and others showing small changes in weight per cent, introduces a sampling error which may account for the differences.

CO_2 has of course increased in all the altered specimens and is present in the form of carbonates. Combined water increased in nos. 2 and 4 and decreased in no. 6. There is one point of interest in this connection: no. 4 shows the greater increase in water and has no hydrous primary minerals; no. 2 shows the lower

increase in water and has one altered hydrous mineral (hornblende) and one unaltered hydrous mineral (biotite); and no. 6, which shows a decrease in water, has two hydrous primary minerals, hornblende and biotite, both of which are altered. Thus it is possible that water need not be introduced in acid rocks to form hydrous secondary minerals.

These conclusions have an important bearing on the interpretation of the minerals cementing the volcanic breccias. As stated before, cementing minerals include abundant quartz, hematite, sericite, and possibly a montmorillonoid. The very small decrease in silica in analyzed specimens suggests that much of the silica in the cement is introduced from another source. Iron oxide (hematite) could have been derived from the altered rocks. The compositions of sericite and montmorillonoid are not known, but include alumina and silica plus potash, soda, or magnesia. These constituents could also have been derived from the altered rocks.

ORIGIN OF PROPYLITIZATION

The early volcanic breccias of the Ebbetts Pass area were deposited by sedimentary agents in large interior basins. Within the altered areas the limits of the early volcanic breccias correspond very closely to the limits of uniform alteration. This, as Curtis (1951) observed, gives a superficial impression that the breccias were altered before extrusion of the overlying massive and autobrecciated flows. However, close inspection showed that the alteration is invariably transitional. Where massive flows overlie breccias their bases are highly altered, but the effects of alteration fade out within 10 feet, except along joints. This strongly suggests that alteration of the breccias occurred after their deposition, or in other words, that the breccias were not propylitized by autohydration, a view supported by lack of alteration in similar breccias higher in the section.

Inspection of figure 2 shows that several intrusive bodies are distributed through both the altered and unaltered rocks. Intrusions in the altered zones consist predominantly of rhyolites and dacites which are themselves highly altered. The large dacite and rhyolite domes of Silver and Highland peaks are unaltered as are the adjacent flows. Bearing in mind that the map unit "Early Andesites" is not equivalent to the early volcanic breccias, a correlation may be established between the occurrence of the early volcanic breccias, intrusive bodies, and propylitization. The andesite neck in the basal conglomerate west of Kinney Peak and the absence of intrusive bodies in the zone of uniform alteration east of Raymond Peak are exceptions to this correlation.

Curtis (1951, p. 133), drawing on similar observations, arrived at the following conclusions: "... it is quite possible that much of the propylitization in the older volcanics occurred after or contemporaneously with the deposition of the younger volcanics, the heat being supplied both by intrusions and extrusions occurring at that time"; and (p. 132), "... it seems probable that regional propylitization of this type is simply the result of general heating of the groundwater ... Rapid circulation of groundwater would be unfavorable to such alteration in that it would tend to keep the temperature down. Thus rocks near the surface would remain unaltered while rocks below the zone of active circulation would be propylitized." It is well to note at this point that Curtis did not correlate the zones of

uniform alteration with the occurrence of the early volcanic breccias. Thus the fact that these may have contained considerably larger quantities of ground water than the younger massive and autobrecciated flows was not considered. Furthermore, the alteration in the Silver Peak region dies out, within 10 to 100 feet of the breccias, less than two-thirds of the way up in a section exceeeding 4,000 feet in thickness. Presumably more than 10 to 100 feet of the younger volcanic rocks, at some time in the history of extrusion of these flows, would have been below the zone of active circulation. Because they were exposed during the very last phase of volcanism to the rhyolite and dacite intrusions of Silver and Highland peaks, it might be supposed that more of them would exhibit propylitization. Perhaps availability of ground water was more important than proximity to the surface in controlling alteration in this particular area.

Figure 3 illustrates the inferred character of the older granodiorite surface and the distribution of breccias and flows in the basins on this surface. This surface controlled drainage of the ground water, directing it to the interior of the basins. At least in the Silver Peak region drainage was not completely internal, for the basement surface also slopes gently to the north. If these breccias, presumably containing abundant ground water, were at any time following extrusion of the first massive flows, heated and supplied with CO_2 by the intrusive bodies now present in the altered zones, large volumes of the breccia might have been propylitized. Lack of alteration of most of the younger volcanic rocks may then be attributed to two factors: absence of large quantities of ground water because of the low porosity of the rocks, and their massive character which may have acted as a barrier against upward migration of heated ground water in the breccias. Alternatively, alteration may have preceded extrusion of all but the lower 100 feet of the younger andesite flows. The two exceptions described above to the correlation may also be explained by this modification of Curtis' hypothesis. The andesite neck west of Kinney Peak is near the prevolcanic crest on the older granodiorite surface so that drainage of ground water would have been away therefrom. The propylitized breccias east of Raymond Peak lie in the Silver Peak basin. The basement surface slopes gently in this direction, so that transfer of heat and CO_2 would have been facilitated by drainage of ground water to the north.

The importance of ground water was twofold. Its presence in the rocks before alteration facilitated movement of material and heat. Again, water entered into the reactions which formed many of the secondary minerals. Where there are few or no hydrous primary minerals, ground water provides a convenient source for the water now combined in the hydrous secondary minerals.

Introduction of heat and CO_2 is, of course, not sufficient to explain all the relationships. Much of the silica in the breccia cement, for example, was probably introduced from a source other than the adjacent altered rocks, but whether or not the intrusive bodies supplied this silica is unknown. Furthermore, if rhyolite and dacite intrusions supplied the heat and CO_2 necessary for the alteration, and addition of water is not necessary to effect propylitization in acid rocks (as suggested on p. 258, we may reasonably ask why the late rhyolite domes are not altered. Part of the answer may be found in the Highland Peak dome. Here the horizontal stratification and the associated flow suggest that the dome is a crater filling.

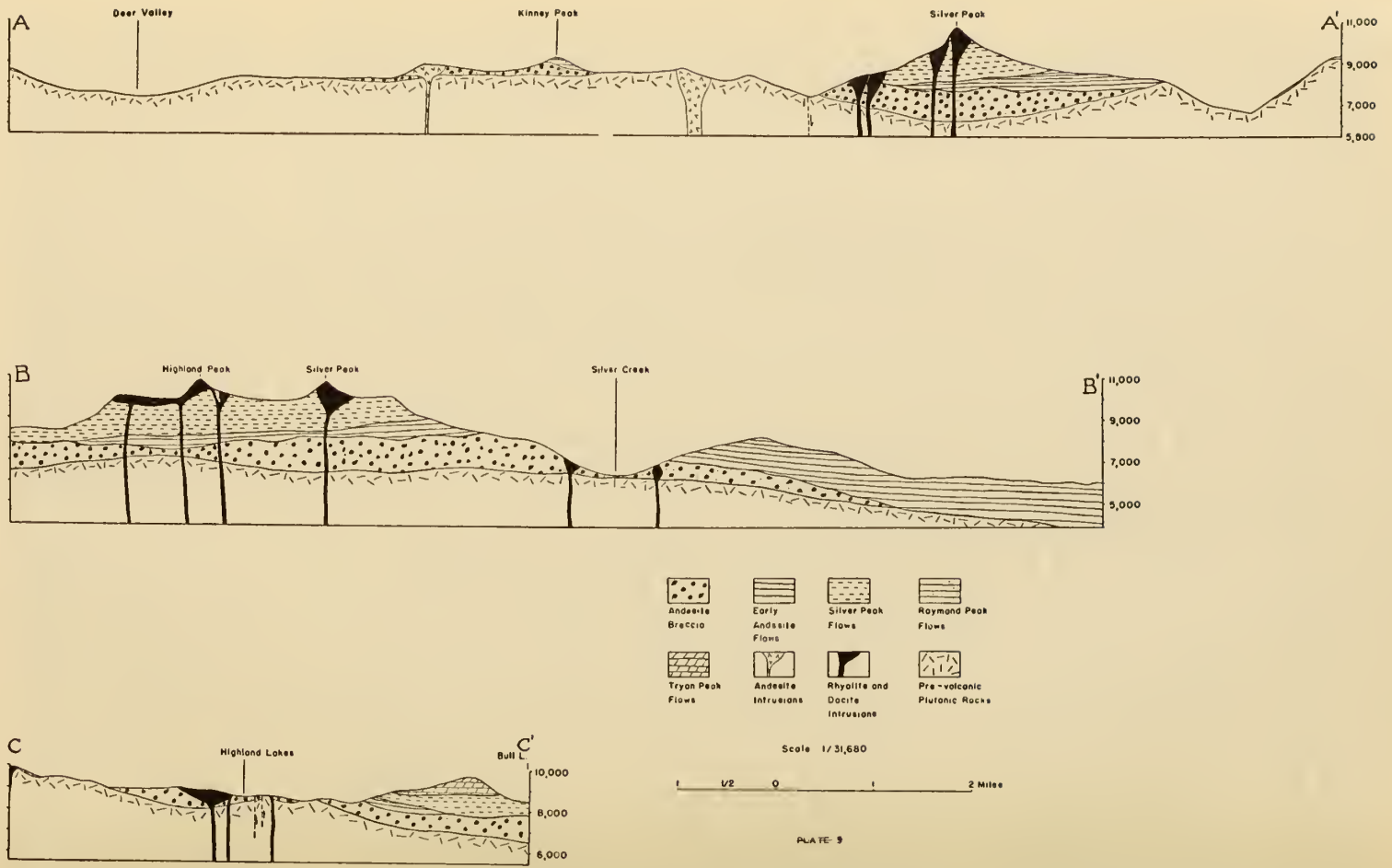

Fig. 3. Cross sections of the Ebbetts Pass region.

According to Curtis' hypothesis, then, these conditions would favor rapid loss of heat and volatiles inhibiting alteration. In addition, the presence of large quantities of water may be necessary to effect movement of material whether or not water enters into a reaction. The depth at which the other domes solidified is not known.

Other Hypotheses

As noted by Coats (1940), a number of hypotheses have been advanced to explain propylitization, and most of these attribute the alteration in some way to volcanic processes. These hypotheses are:

1. Autohydration or deuteric alteration. The alteration is caused by solutions concentrated in the last stages of crystallization of the altered rock itself.
2. Hydrothermal alteration by solutions derived from unerupted magma.
3. Hydrothermal alteration by ore-bearing solutions either related to volcanic processes or vaguely described as postvolcanic.

It is recommended that Curtis' hypothesis, hydrothermal alteration by ground water heated and enriched in CO_2 by intrusive magmas, be added to this list.

This process of alteration did not operate in the Ebbetts Pass region to the exclusion of all others. Although deuteric alteration cannot satisfactorily explain the alteration of the volcanic breccias, this process may have operated in the intrusive bodies. The effect of solutions derived from subjacent magma cannot be distinguished from the contributions of the intrusive bodies. The distinction between these two hypotheses is a very small one and rests chiefly on the importance attached to ground water. As Curtis noted, all the mineralized zones in this area lie within the propylitized rocks, but there does not seem to be a direct connection between mineralization and propylitization, for there is no increase in intensity of alteration as the mineralized zones are approached. Actually, this is true of the intrusive bodies, so that we may appeal in either hypothesis to the efficacy of ground water in distributing heat and CO_2 derived from a source in which these are relatively concentrated. Lastly, silicification of the country rock is commonly severe around the mineralized zones, but the distinction between this and the barren quartz cements of the volcanic breccias need not be genetic.

CONCLUSIONS

Secondary minerals of propylitized rocks cannot be described briefly without oversimplifying their variations. The variations in secondary minerals which replace the same primary mineral are divided into two types: variations within a given rock type, commonly within the limits of a thin section; and variations between different rock types. The first type may be attributed to variation in the original composition of primary minerals, changes in composition of the altering solutions owing to local interactions between solutions and solid rock, and an apparent effect due to the way thin sections are cut. The second type is usually expressed in the occurrence of sericite replacing most of the primary minerals in or near acid rocks. This is attributed to two factors: difference in initial composition of the primary minerals which occur in a wide range of rock types (plagioclase, hornblende and, to a lesser extent, clinopyroxene and biotite); and movement of potash and/or soda both within the acid rocks and beyond their limits into

adjacent andesites and basalts. All these variations are local and cannot be satisfactorily explained by different periods of alteration. Thus, sericitization and propylitization differ mineralogically only because different rock types are involved in the alteration, not because a "pervasive sericitization" occurred at one period and a "pervasive propylitization" at another period in the history of these rocks. The same conclusions may apply to the silicification related (?) to ore deposition.

Excepting silica, most of the material making up the cement of the early volcanic breccias was probably derived from the altered rocks. The source of silica is not known.

There are no unambiguous criteria supporting any single cause of propylitization. The geologic relations indicate, however, that ground water probably played an important part in the alteration, especially as a medium through which heat and CO_2 were transferred to the altered rocks. The source of heat and CO_2 may have been either intrusive bodies, ore-bearing solutions, or both. On the other hand, all the solutions may have been derived from subjacent magmas as described by Kato (1931). It is interesting to note that the geologic relations in Kato's area (Idzu Province, Japan) are remarkably similar to those in the Ebbetts Pass region, so that ground water may have played a part in the propylitization described by Kato. Certainly, the evidence is strongly against autohydration as a principal cause of propylitization in th Ebbetts Pass region.

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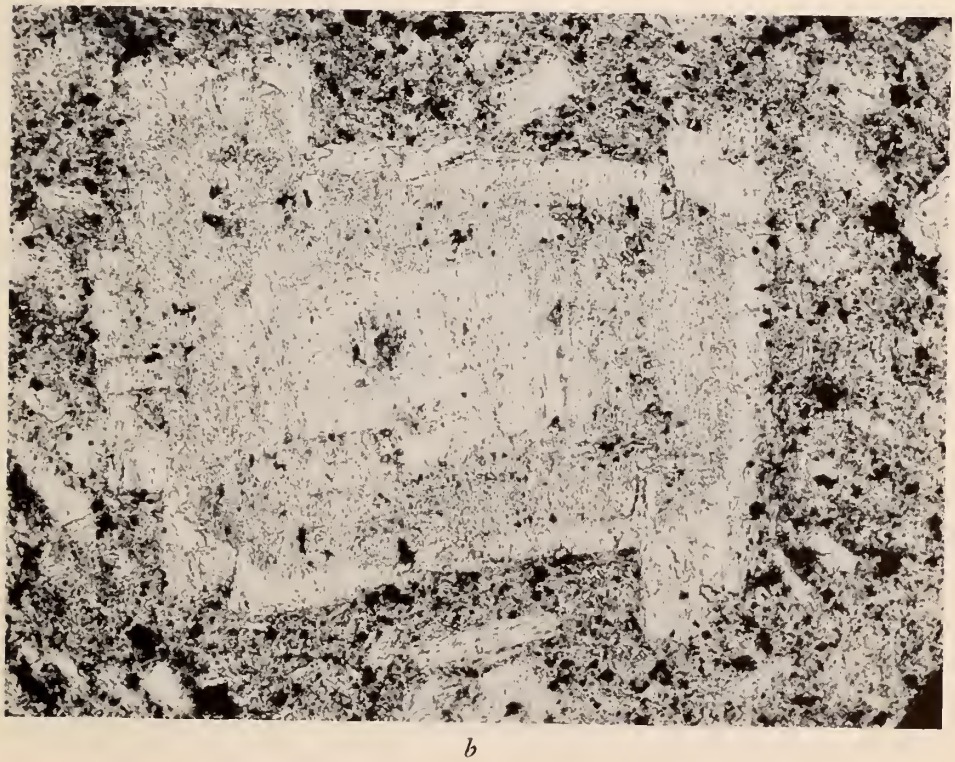
PLATES

PLATE 33

a. Cleavage traces of a chlorite-carbonate pseudomorph after hornblende preserved by minute grains of epidote. Opaque rim, in part magnetite, formed before propylitization. Under plane polarized light. × 65.

b. Original zonal structure of a feldspar aggregate preserved by coarse sericite in the core and border zones, fine sericite, iron ore and a montmorillonoid (?) in the intermediate zone. Under plane polarized light. × 85.

a

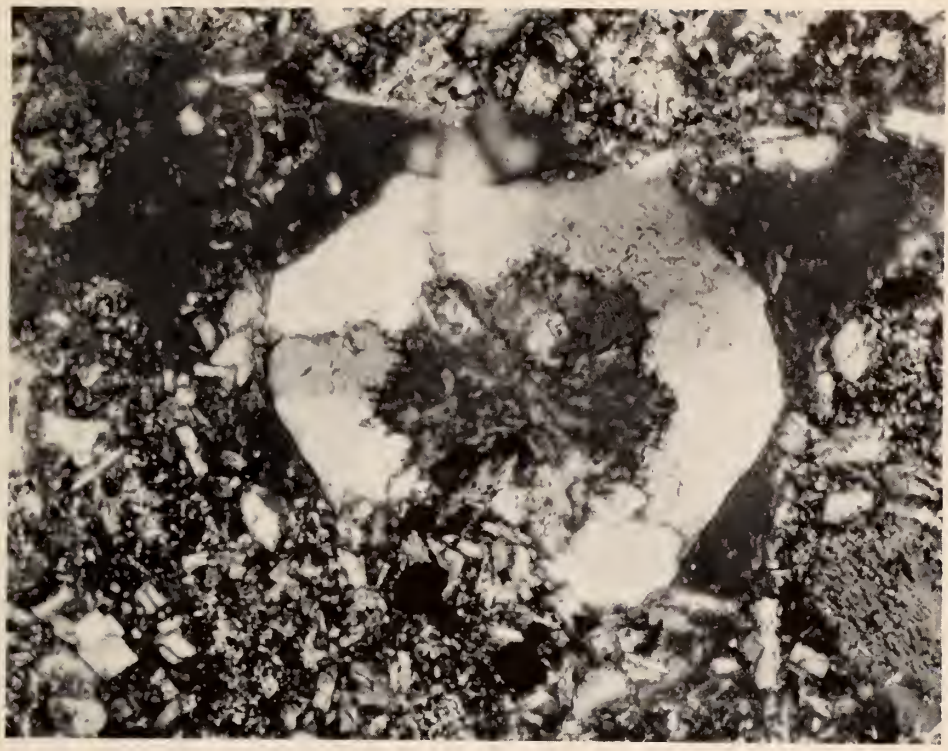


b

PLATE 34

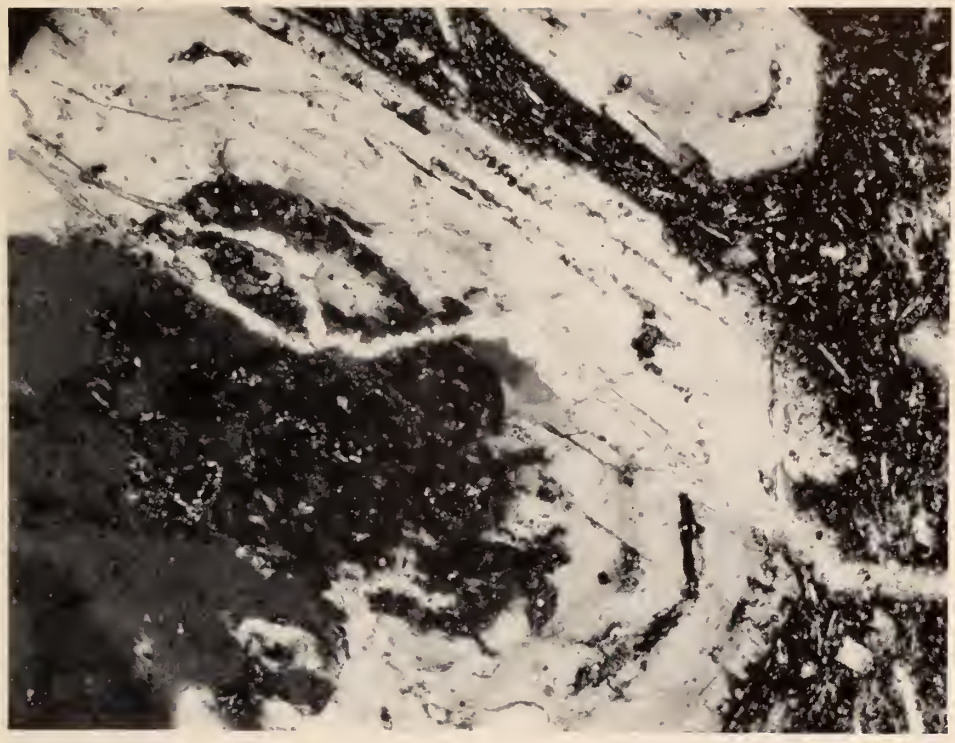
a. Replacement of cristobalite by granular quartz with sutured grain boundaries. Undulatory extinction across grain boundaries and within grains across sealed sutures. Under crossed nicols. × 165.

b. Chlorite-carbonate-epidote pseudomorph after hornblende with an unaltered biotite core. Epidote occurs as very small grains scattered through the chlorite. Under plane polarized light. × 105.



a

b

PLATE 35

Minor replacement of a zoned plagioclase phenocryst along a carbonate veinlet. Core of the phenocryst is replaced by a very finely divided pale green montmorillonoid (?). Under crossed nicols. × 105.